Re–Os geochronology of Cu and W–Mo deposits in the Balkhash metallogenic belt, Kazakhstan and its geological significance

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\begin{abstract}
The Central Asian metallogenic domain (CAMD) is a multi-core metallogenic system controlled by boundary strike-slip fault systems. The Balkhash metallogenic belt in Kazakhstan, in which occur many large and super-large porphyritic Cu–Mo deposits and some quartz vein- and greisen-type W–Mo deposits, is a well-known porphyritic Cu–Mo metallogenic belt in the CAMD. In this paper 11 molybdenite samples from the western segment of the Balkhash metallogenic belt are selected for Re–Os compositional analyses and Re–Os isotopic dating. Molybdenites from the Borly porphyry Cu deposit and the three quartz vein-greisen W–Mo deposits—East Kounrad, Akshatau and Zhanet—all have relatively high Re contents (2712–2772 \textmu g/g for Borly and 2.267–31.50 \textmu g/g for the other three W–Mo deposits), and lower common Os contents (0.670–2.696 ng/g for Borly and 0.0051–0.056 ng/g for the other three). The molybdenites from the Borly porphyry Cu–Mo deposit
\end{abstract}
1. Introduction

The Balkhash metallogenic belt lies at the inner margin of the U-shaped Kazakhstan—Tianshan orocline and the core of the Balkhash—Junggar orogenic belt of the Central Asian metallogenic domain (CAMD; also called the Paleo-Asian metallogenic tectonic system; Chen et al., 2009; Fig. 1). It is the main porphyry copper mineralization area in Kazakhstan, and one of the ten most important porphyry Cu metallogenic belts in the world (He and Zhu, 2006; Zhu et al., 2007). The Kounrad Cu deposit in the belt is one of the world’s ten largest porphyry Cu deposits, the formation of which is mainly related to tectono-magmatism in the later stage of the relic ocean basin’s extinction during the Devonian—Carboniferous. Other noteworthy deposits in the region include the super-large porphyry Aktogay Cu—Mo deposit and the large skarn Sayak Cu-polymetallic deposit (Li et al., 2007). Furthermore, there are also porphyry Borly Cu—Mo deposit and the East Kounrad, Akshatau, and Zhanet quartz vein-greisen W—Mo deposits in the belt.

Molybdenite can provide information critical to understanding sulfide mineral deposition in ore systems; this information is not recorded by other isotopic systems in alteration minerals (Selby and Creaser, 2001). Re—Os isotopic dating of molybdenites is considered to be a high-accuracy dating method usable for direct determination of metallogenic age (Mao et al., 2003, 2006; Du et al., 2007; Nie et al., 2007). Based on the Re—Os dating of molybdenites, this paper defines ages of the Late Paleozoic porphyry Cu—Mo metallogenesis and quartz vein-greisen W—Mo mineralizations in the Balkhash metallogenic belt. In addition, it also correlates them with the ages of East and West Junggar and the East Tianshan porphyry Cu metallogenic belts in China.

2. Geology of the Balkhash metallogenic belt in the Central Asian metallogenic domain

2.1. The Central Asian metallogenic domain

The Central Asian metallogenic domain begins in the west in the Ural Mountains on the Euro-Asia boundary, and extends eastwards through Kazakhstan, Uzbekistan, parts of Kyrgyzstan, Xinjiang, Qinghai, northern Gansu, western Inner Mongolia, and western Mongolia to the southern Siberia region. In the latter area, it also includes the eastern part of Lake Baikal, consisting of the Sayan—Erguna—Xinkai orogen, the Tianshan—Xing’an Hercynian orogen, the Ural—South Tianshan Hercynian orogen, the Tarim para-platform, and partial Yanshanian orogens on the eastern margin of Asia (Chen et al., 2009; Fig. 1). Multi-stage and multi-type zones of volcanic rocks, granites, basic rocks, ultrabasic rocks, ophiolites, and metamorphic rocks are distributed in this metallogenic domain. Geologically, this domain has experienced the formation of continental basement, pericontinental accretion of the Paleo-Asian Ocean, and continental margin activities in the western Pacific, as well as the elevation and subsidence of intracontinental blocks resulting in the presence of various environments favorable to the formation of ore (Chen et al., 2009). The Central Asian metallogenic domain is world famous for its metallic and non-metallic deposits, the ore-forming processes of which are extremely complicated and diversified (He and Zhu, 2006; Zhu et al., 2007). The mineralizations of porphyry Cu—Mo and quartz vein-greisen W—Mo deposits occupy a particularly important place in these processes.

The main body of the Central Asian metallogenic domain is the Balkhash—Junggar—South Mongolian porphyry Cu(Mo) metallogenic belt (Li et al., 2007), in which there are many porphyry deposits: Tsagaan Suvarga and Oyu Tolgoi in Mongolia; the Kounrad, Aktogay, Koksal, and Borly in Kazakhstan; the Olmaliq in Uzbekistan; the Baogutu in West Junggar; and the Tuwu-Yandong in the East Tianshan Mountains, etc. (Fig. 1). Most of these deposit formed during the Carboniferous—Permian, although some are of Early Paleozoic age.

2.2. The Balkhash metallogenic belt

The Balkhash metallogenic belt is one of the cores of the Central Asian metallogenic domain (Zhu et al., 2007), and is also a part of the (circum-)Balkhash-(circum-)Junggar-South Mongolian porphyry Cu(Mo) metallogenic belt (Li et al., 2007). The formation of its Late Paleozoic porphyry Cu deposits is related to Devonian and Carboniferous—Permian volcano-magmatic arcs in the region (Li et al., 2008). This metallogenic belt consists of north and south zones of mineralization. The former begins at the Moity block in the west, and extends eastwards via Aktogay to Baotugtu, western Junggar, Xinjiang, China. It is about 1000 km long from east to west and contains nearly one hundred deposits of various sizes that have already been discovered, amongst which are both the Kounrad (with Cu reserves > 8 Mt) and Aktogay (Cu = 5.88 Mt), two world famous super-large porphyry Cu—Mo deposits. The Borly porphyry Cu deposit and the quartz vein-greisen W—Mo deposits such as Akshatau, East Kounrad, and
The Borly porphyry Cu deposit is situated in the Proiziony district, Dzhezkazgan Province, 60 km north of Balkhash City, and 45 km away from the Kounrad Cu deposit, at N 47°11′4′′, E 74°42′41″, and at an elevation of ~493 m a.s.l. It lies mainly in the southern part of the Tokrausky synclinorium, and its Cu reserves amount to some 600 kt Cu @ 0.34%, and a total Cu:Mo ratio = 33:1. The rocks in the deposit are dominated by aplitic rhyolite–dacite tuff. These include (1) a suite of lithic-crystal tuff, lava, and subvolcanic rocks of the Lower Carboniferous Karkaralinskaya Formation, and (2) a suite of dacite, sometimes trachdacite or andesite–dacite ignimbrite, microlitic tuff, tufflava, lava, and subvolcanic rocks of the Upper-Middle Carboniferous Keregetass Formation. The center of the Borly deposit is the Borlinksy apophysis of the Kyzylzhalsky intrusion. The Borlinksyaya apophysis contains three petrofacies—the first being quartz diorite, the second (and the main one) being biotite amphibole granodiorite, and the third, light-colored granite-porphry. These petrofacies are cut by a granodiorite pluton with a complex dendritic texture. The intrusion of that rock body was accompanied by intensive cryptoexplosive brecciation, hydrothermal alteration, and formation of quartz-sulfide stockworks. The youngest magmatic assemblage is the alkaline granite-porphyry dikes and subvolcanic rocks in the Early Permian Zhaksitagalinsky complex (Abdulin et al., 1998).

3.2. The Akshatau W–Mo deposit

The Akshatau large-scale quartz vein-greisen W–Mo deposit occurs in the Paleozoic orogen in Central Kazakhstan, 150 km from Balkhash City, at N 47°58′52″, E 74°3′22″, at an elevation of approximately 740 m. It is a disseminated quartz vein-greisen Be–W–Mo deposit (Yefimov et al., 1990), having resources as follows: 2.741 × 10^6 t (first-grade reserves) of 0.50% WO_3; 6.55 × 10^7 t of 0.1%–0.3% WO_3; 1.75 × 10^7 t of 0.04%–0.07% Mo; and 1.60 × 10^7 t of 0.03%–0.07% Be.

As part of the Permian Akshatau metallogenic province, the deposit is located in the rear part of a volcano-intrusive zone into a flysch belt in the Late Paleozoic continental margin. It is controlled by linear and circular faulted structures, and by the intersection by structural belts of different trends (Burmistrov et al., 1990). It occurs within Permian leucogranites of the Akshatau multi-stage complex that intrude Silurian sandstones. Greisen-quartz vein type W–Mo deposits are closely related to the tops of ore-forming intrusives in both endocontacts and exocontacts. The greisen bodies consist of root, intermediate, and front zones. Most lie within the intermediate zone, occurring inside granite cupolas or at their wings and ridges of different sizes. Enriched deposits are most easily found at the tops of granites in mono-dome structures (Daukeev et al., 2004). The ore-forming process has mainly undergone 2 stages and 4 phases: the first stage is the pneumatolytic–hydrothermal stage, comprising the molybdenite–quartz phase (440–340 °C) and a complex rare-metal phase (480–250 °C); the second stage is the real hydrothermal stage, containing the galena–sphalerite–quartz phase (310–150 °C) and the calcite–fluorite–quartz phase (180–60 °C) (Yefimov et al., 1990).

3.3. The East Kounrad W–Mo deposit

The East Kounrad W–Mo deposit lies about 11 km east of the Kounrad porphyry Cu deposit, at N 47°1′8″, E 75°8′6″, and an elevation of about 432 m. It is an underground-mined post-magmatic pegmatite-quartz vein type W–Mo deposit, which played a role during the Second World War, but is now abandoned. It has reserves of 200–250 kt of Mo, with a grade of 0.056%. It is of the quartz vein-greisen type with the major ore minerals being wolframite and molybdenite (Fig. 3). The W–Mo mineralizations
Figure 2  Regional geological sketch map of the western Balkhash metallogenic belt 1-Quaternary System; 2-Permian System; 3-Carboniferous–Permian System (undivided); 4-Carboniferous System; 5-Devonian System; 6-Silurian System; 7-Precambrian System; 8-Triassic granitoids; 9-Permian granitoids; 10-Carboniferous granitoids; 11-Devonian granitoids; 12-Ordovician granitoids; 13-Precambrian granitoids; 14-the Balkhash Lake area; 15-thrust fault; 16-dextral strike-slip fault; 17-fault; 18-locations of deposits studied in this paper.
occur mainly in quartz veins and quartz veinlets, and also at the tops of cupolas and in greisens surrounding quartz veins (Burmistrov et al., 1990). The main mineral assemblages of the deposit are: scheelite, wolframite, molybdenite, apatite, phenakite, beryl, biotite, muscovite, bismite, bismuthinite, calcite, chalcopyrite, ferromolybdite, fluorite, prosopite, helvite, microcline, pyrite, phlogopite, powellite, quartz, rhodochrosite, salite, and topaz.

### 3.4. The Zhanet Mo deposit

The Zhanet Mo deposit is a medium-sized quartz vein-greisen Mo deposit, located at N 47°31′17″, E 74°18′55″, and an elevation of approximately 618 m. It was first explored in 1948, and mined for some time, but at present mining has been temporarily suspended. The ores contain molybdenite, wolframite, topaz, fluorite, and beryl. The main ore mineral is molybdenite (Fig. 4), which also has high contents of rare-earth and rare elements. Molybdenites occur mainly in Mo-bearing granite-porphyries and in late-stage quartz veins and fissures assuming disseminated and veined shapes. In the late-stage quartz veins the molybdenites are associated with fluorite. Wall-rock alterations include potassic-alteration (e.g. K-feldspathization, biotitization), pyritization, greisenization, and epidotization. Pegmatite veins formed in the late stage. The age of the ore-forming granites in the deposit is post-Middle Carboniferous.

### 4. Re–Os isotopic compositions of the molybdenites

#### 4.1. Sample processing and analytical methods

The 11 molybdenite samples used for Re–Os isotope dating were collected from the Borly porphyry Cu deposit, the Akshatau W–Mo deposit, the East Kounrad W–Mo deposit, and the Zhanet Mo deposit in the western section of Kazakhstan’s Balkhash metallogenic belt. After grinding and sorting, all the molybdenite samples reached the purity (>98%) and homogeneity required—with a grain size of 200 meshes—for the purpose of reducing the effect of decoupling (Stein et al., 2001, 2003; Du et al., 2007). Re–Os isotope dating of the molybdenite samples was performed at the Re–Os Isotope Chronology Laboratory, National Research Center for Geoanalysis. The chemical separation and processing processes of Re and Os as well as the mass spectrometry technology have been described by Du et al. (1994, 2001, 2004) and Qu and Du (2003, 2004). The isotope ratio was determined using the TJA X-series ICP-MS at the National Research Center for Geoanalysis. For Re, the mass numbers 185 and 187 were chosen and 190 was used to monitor Os. For Os, 186, 187, 188, 189, 190 and 192 were chosen, and 185 was used to monitor Re.

The common Os was obtained from the measured ratio of \( ^{192}\text{Os} / ^{190}\text{Os} \) following the table of atomic weight (Wieser, 2006) and the table of isotope abundances (Bohlke et al., 2005). The uncertainties of Re and Os contents consisted of the weighing errors of the samples and diluents, the nominal errors of the diluents, the correction errors of fractionation in mass spectrometry, and the measurement errors of isotope ratios of the samples. The confidence level was 95%. The uncertainties of model ages also included the uncertainty of the decay constant (1.02%), and the confidence level was also 95%. The model age \( t \) (Ma) of molybdenites was calculated according to the formula given by Du et al. (1994) and Qu and Du (2003), where \( 1.666 \times 10^{-11} \text{ yr}^{-1} \) (Simoliar et al., 1996) was taken for the decay constant of \(^{187}\text{Re}\). Ludwig’s (2003) method was used to process the Re and Os isotope data relating to molybdenites, and obtain the isochron ages of Re–Os.

#### 4.2. Analytical results

The analytical results are listed in Table 1. The table also gives the measured results of the standard material GBW04436 (JDC) and its certified values (Du et al., 2004). Table 2 provides the blank background of the whole procedure of the analyses.

### 5. Results and discussions

#### 5.1. Metallogenic ages and series of Cu–W–Mo deposits in the Balkhash metallogenic belt

The model ages of molybdenites obtained in the experiment are 316.1 ± 7.0 Ma and 315.6 ± 5.9 Ma, averaging 315.9 Ma for the Borly porphyry Cu deposit; 297.8 ± 5.3 Ma, 297.9 ± 4.5 Ma, 297.9 ± 4.4 Ma, and 298.4 ± 4.1 Ma, averaging 298.0 Ma for the East Kounrad W–Mo deposit; 295.2 ± 5.3 Ma, 295.8 ± 4.3 Ma, and 294.1 ± 4.3 Ma, averaging 295.0 Ma for the Zhanet Mo deposit.
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<th>187 Os (ng/g)</th>
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<td>Measured</td>
<td>Measured</td>
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<td>090414−17</td>
<td>xh080912-9(1)</td>
<td>0.00118</td>
<td>2712</td>
<td>50</td>
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<td>3.004</td>
<td>1742 25</td>
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<td>090330−10</td>
<td>xh080910-11(3)</td>
<td>0.05070</td>
<td>26.19</td>
<td>0.34</td>
<td>0.0051</td>
<td>0.227</td>
<td>16.46 0.22</td>
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<td><em><em>Certified values</em> of the measured values of the standard material GBW04436 (JDC) (Du et al., 2004)</em>*</td>
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Note: The measurements were done at the Re-Os Isotope Chronology Laboratory, National Research Center for Geoanalysis.
deposit; and 291.1 ± 4.0 Ma and 287.5 ± 4.4 Ma, averaging 289.3 Ma for the Akshatau W–Mo deposit. Among them, the Re–Os isochron age for the deposits such as East Kounrad, Akshatau and Zhanet is (297.9 ± 0.99/–3.4) Ma, and the MSWD value is 0.97 (Fig. 5). All of the above ages are greater than the metallogenic ages of the Akshatau and East Kounrad W–Mo deposits previously reported (which are ~285 Ma and 285–283 Ma; He and Zhu, 2006).

The Re–Os isochron dating of molybdenites is considered to be a high-accuracy dating method usable for direct determination of the metallogenic age (Mao et al., 2003, 2006; Du et al., 2007; Nie et al., 2007). The formation ages of the East Kounrad W–Mo deposit, Akshatau W–Mo deposit, and Zhanet Mo deposit are of the same period, their molybdenites come from the same material source, and the Re–Os isotope system can be regarded as under a closed status, so they, therefore, agree with the determination criterion of isochron ages of isotopes (Nie et al., 2007). The Re–Os isochron ages given in the present paper represent the ages of the quartz vein-greisen W–Mo mineralization in the western Balkhash metallogenic belt.

The analytical results of Re–Os isochron dating of molybdenites indicate that the mineralization related to Cu–W–Mo in the western Balkhash metallogenic belt took place during the interval 315.9–289.3 Ma. The formation ages of Cu–W–Mo deposits can be divided into two stages: the first stage is that of porphyry Cu–Mo deposits, occurring at ~316 Ma; the second, of quartz vein-greisen W–Mo deposits, occurring at ~298 Ma. Thus, Cu–W–Mo mineralization in the western Balkhash metallogenic belt has resulted in a metallogenic series with porphyry Cu–Mo deposits in the early stage and quartz vein-greisen W–Mo deposits in the late stage.

### 5.2. Characters of Re–Os isotope systems of Cu–W–Mo deposits in the Balkhash metallogenic belt

Re–Os data is available for a number of ore deposits (Lambert et al., 1999), among them mantle-sourced materials (xenoliths, komatiites, and basalts), sulfides-bearing sediments, a series of magma-sulfides deposits including the Ni deposit associated with komatiites (Kambalda), the Cu–Ni deposit associated with basalts/gabbros (Sudbury, Noril’sk-Talnakh, and Duluth), and the PGE-rich deposit associated with basalts/gabbros in basic and ultrabasic layered intrusives (e.g. J–M Reef, Stillwater; Fig. 6). In contrast, the molybdenites from the Borly porphyry Cu deposit and the three quartz vein-greisen W–Mo deposits—East Kounrad, Akshatau, and Zhanet—have relatively higher Re contents (2712–2772 μg/g for Borly and 2.267–31.50 μg/g for the other three W–Mo deposits), and lower common Os contents (0.670–2.696 ng/g for Borly and 0.0051–0.056 ng/g for the other three). Therefore, they have very high Re/Os ratios (1.006 × 10^6–4.137 × 10^6 for Borly and 4.048 × 10^4–5.135 × 10^5 for the other three).

Just as magmatogenic sulfide-bearing rocks (and ores) have similar but slightly lower Re/Os ratios when compared with their parent silicate magmas (Lambert et al., 1999), the magma source rocks of the porphyry Cu–Mo deposits and quartz vein-greisen W–Mo deposits in the Balkhash metallogenic belt have higher Re/Os ratios. Hence, the mantle melts of this region had very high Re/Os ratios.

We can see in the diagram of Re/Os ratios vs. common Os contents that the molybdenites from the porphyry Cu–Mo deposits and from the quartz vein-greisen W–Mo deposits fall in different zones, which indicates that the two mineralizations had different paths (Fig. 6). The former (mineralization of porphyry Cu–Mo deposits) has suffered contamination of more crustal materials while the latter is more directly related to the mantle process. Nevertheless, they may have come from the same mantle source region.

### 5.3. Tectono-magmatism and metallogenic ages in the Balkhash–Junggar metallogenic belt

The metallogenic series of Cu–W–Mo deposits in the western Balkhash metallogenic belt may reflect the evolutionary process of magmatism in the lithosphere of a mobile continental margin controlled by polycycle geodynamics and an orogenic history of multi-stage subduction, crustal accretion, and lateral growth in the core part of Central Asia during the Paleozoic, especially the Middle and Late Paleozoic (Heinhorst et al., 2000; Heubeck, 2001; Xiao et al., 2008, 2009). It developed for multiple reasons—from the tectonic setting of a back-arc ocean (volcano-massive sulfide Cu–Au deposits), to the cal-alkaline magmatism controlled by subduction (porphyry Cu deposits), and to the crustal differentiation of low-grade partial melting and internal separation of magma in a broad sense (porphyry Mo deposits and quartz vein-greisen W–Mo deposits), and finally to the setting of a nonorogenic

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**Table 2** Blank background of the whole procedure of analyses.

<table>
<thead>
<tr>
<th>Serial Nos.</th>
<th>Original sample Nos.</th>
<th>Re (ng)</th>
<th>Common Os (ng)</th>
<th>187Os (ng)</th>
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**Figure 5** Re–Os isochron diagram of the molybdenites from quartz vein-greisen W–Mo deposits in the western Balkhash porphyry Cu–Mo metallogenic belt. The zero intercept on the 187Os axis is expected because molybdenite contains no initial or common 187Os (Morgan et al., 1968; Markey et al., 1998).
Permian continental rift valley (the peralkaline riebeckite granite REE—Zr—Nb-enriched system; Heinhorst et al., 2000).

Some areas of China, e.g. East and West Junggar and the East Tianshan Mountains of Xinjiang and Inner Mongolia, also developed banded porphyry Cu–Mo and quartz vein-greisen W–Mo (Sn) metallogenic belts, which are of similar age and type to the Balkhash metallogenic belt. For example, the Paleozoic Baogutu porphyry Cu–Mo deposit in the southern Darabut island-arc of West Junggar occurs in rock body V of Baogutu, from which LA ICP-MS dating has yielded a zircon U–Pb age of quartz diorite porphyry of 309.9 ± 1.9 Ma (Tang et al., 2009). Sulfide minerals of Cu, Fe, Mo, and Zn were formed at an early stage (Shen et al., 2009), in which the Re–Os age of molybdenite is 310 Ma (Song et al., 2007). The Beierkuduke quartz vein-greisen Sn deposit in East Junggar also occurs in Late Carboniferous granites, with a metallogenic age of 296.3 ± 2.6 Ma (Tang et al., 2006; K–Ar age of muscovite). In the Sareshike Sn deposit of East Junggar, the Re–Os age of molybdenite is 307 ± 11 Ma (Tang et al., 2007). The Tuwu-Yandong porphyry Cu deposit in the East Tianshan Mountains occurs in a plagiogranite porphyry that is Carboniferous (334 ± 3 Ma to 333 ± 4 Ma; Chen et al., 2005), and the Re–Os isochron age of molybdenite in the copper ore body is 323 ± 2 Ma (Rui et al., 2002). The Chihu porphyry Mo–Cu deposit in the East Tianshan Mountains also occurs in a plagiogranite porphyry intrusion, and zircon SHRIMP U–Pb dating reveals its crystallization age to be 322 ± 10 Ma (Wu et al., 2006).

It can thus be seen that the metallogenic age of the porphyry Cu–Mo deposit in the western Balkhash metallogenic belt (315.9 Ma, the Borly Cu deposit) is between that in the East Tianshan Mountains (323 ± 2 Ma, the Tuwu-Yandong porphyry Cu deposit, Rui et al., 2002; 322 ± 10 Ma, the Chihu porphyry Mo–Cu deposit, Wu et al., 2006) and that in West Junggar (310 Ma, the Baogutu porphyry Cu–Mo deposit, Song et al., 2007). On the other hand, the metallogenic age of quartz vein-greisen W–Mo deposits in the western Balkhash metallogenic belt (297.9 Ma) is younger than or identical with that of quartz vein-greisen Sn deposits in East Junggar (307 ± 11 Ma, the Sareshike Sn deposit, Tang et al., 2007; 296.3 ± 2.6 Ma, the Beierkuduke Sn deposit, Tang et al., 2006). In summary, the mineralizations of large-scale porphyry Cu–Mo deposits in the western Balkhash–Junggar metallogenic belt of the Central Asian metallogenic domain were concentrated in the interval of 323–310 Ma of the Late Carboniferous, whereas younger quartz vein-greisen W–Mo(Sn) deposits occurred between 297.9 Ma and 296.3 Ma, and were products of late Hercynian tectono-magmatism.

![Re/Os vs. Os diagram of molybdenites from the western Balkhash porphyry-type Cu–Mo metallogenic belt Re/Os concentration ratio calculated using common Os.](image)

The age of Balkhash–Junggar porphyry Cu–Mo mineralization in the Central Asian metallogenic domain agrees well with that of post-collisional plutonism in East and West Junggar in the Late Paleozoic (Han et al., 2006). It is obviously younger than the metallogenic age of the Elegen porphyry Mo(Cu) deposit in Beishan Mountain, Inner Mongolia, which occurred in a Late Paleozoic island-arc environment (332.0 ± 9.0 Ma, Re–Os isochron age of molybdenites; Nie et al., 2005). On the other hand, the age of the quartz vein-greisen W–Mo(Sn) mineralization in the Balkhash–Junggar porphyry Cu–Mo metallogenic belt coincides with that of post-collisional plutonism in the Late Paleozoic in East and West Junggar (Han et al., 2006). It is slightly older than the age of (1) Cu–Ni sulfide deposits in East Junggar that formed under a post-collisional extension environment (e.g. the Re–Os isochrone ages of the No. 1 and No. 2 intrusive bodies of the Karatungk deposit, and Cu–Ni sulfide ore of the Huangshandong deposit in the East Tianshan Mountains are 282.5 ± 4.8, 290.2 ± 6.9 and 284 ± 14 Ma respectively; Zhang et al., 2008), and (2) the Kanggur gold deposit in the East Tianshan Mountains. The latter is controlled by a ductile shear zone (Rb–Sr and Sm–Nd isochrons give the main stage as 290–282 Ma and a late stage as 275–254 Ma; Zhang et al., 2003). Porphyry Mo deposits and pegmatite-type rare-metal deposits were also later formed in the Hercynian Uralide orogen. For example, the quartz–molybdenite stocks in the Malyshovo leucogranite stocks...
and the molybdenites in the hornfels surrounding the stocks hosted in the Shameika porphyry Mo deposit in the Uralide orogen yielded Re–Os isochron ages of 273 ± 5 Ma and 282 ± 6 Ma, respectively, while the molybdenites from the pegmatite-hosted Lipovy Log Ta–Nb–Mo deposit gave an isochron age of 262.0 ± 7.3 Ma (Mao et al., 2003).

6. Conclusions

The Balkhash metallogenic belt is an important porphyry Cu–Mo metallogenic belt in the multi-core metallogenic system of the Central Asian metallogenic domain. This paper, based on (1) Re–Os analyses of 11 molybdenite samples from the Balkhash–Akshatau region in the western Balkhash metallogenic belt, and (2) a preliminary correlation between the East–West Junggar and the East Tianshan metallogenic belts, has reached the following conclusions:

(1) The model Re–Os ages (mean values) of the Borly porphyry Cu (Mo) deposit, and the East Kournard, Zhonet, and Akshatau quartz vein-greisen W–Mo deposits are 315.9 Ma, 298.0 Ma, 295.0 Ma, and 289.3 Ma, respectively, amongst which the latter three deposits have a Re–Os isochron age of (297.9 ± 0.99)/3.4 Ma) and an MSWD value of 0.97;

(2) Re–Os ages of molybdenites reveal that the Cu–W–Mo mineralization of the Balkhash metallogenic belt occurred during 315.9 Ma to 289.3 Ma. The formation of Cu–W–Mo deposits can be divided into two stages: the first, of porphyry Cu–Mo deposits occurring at ~316 Ma; and latter, quartz vein-greisen W–Mo deposits at ~298 Ma;

(3) It is inferred on the basis of model and isochron ages of molybdenites that the formation of metallogenic granite-porphyry and pegmatite is roughly synchronous with that of the corresponding deposits in the region—all being of Late Carboniferous age, the products of late Hercynian tectono-magmatism;

(4) A correlation of the Balkhash deposit with East–West Junggar and the East Tianshan porphyry Cu ore belts in China shows that large-scale metallogenesis of porphyry Cu–Mo in the Central Asian metallogenic domain was concentrated between 323 and 310 Ma, whereas that of quartz vein-greisen W–Mo(Sn) deposits occurred between 297.9 Ma and 296.3 Ma, the products of late Hercynian tectono-magmatism.

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Re–Os geochronology of Cu and W–Mo deposits in the Balkhash metallogenic belt, Kazakhstan

123


